Status of the next-generation OpenGGCM

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Outline

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3. Results
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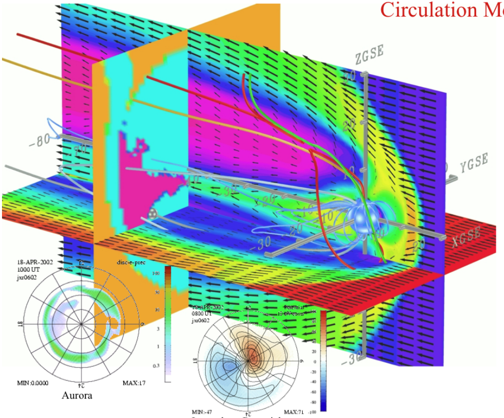
Legacy OpenGGCM

OpenGGCM: Global Magnetosphere Modeling

The Open Geospace General Circulation Model:



- Coupled global magnetosphere - ionosphere - thermosphere model.
- 3d Magnetohydrodynamic magnetosphere model.
- Coupled with NOAA/SEC 3d dynamic/chemistry ionosphere - thermosphere model (CTIM).
- Coupled with inner magnetosphere / ring current models: Rice U. RCM, NASA/GSFC CRCM.
- Model runs on demand (>300 so far) provided at the Community Coordinated Modeling Center (CCMC at NASA/GSFC). http://ccmc.gsfc.nasa.gov/
- Fully parallelized code, real-time capable. Runs on IBM/datastar, IA32/I64 based clusters, PS3 clusters, and other hardware.
- Used for basic research, numerical experiments, hypothesis testing, data analysis support, NASA/THEMIS mission support, mission planning, space weather studies, and Numerical Space Weather Forecasting in the future.
- Funding from NASA/LWS, NASA/TR&T, NSF/GEM, NSF/ITR, NSF/PetaApps, AF/MURI programs.

Personnel: J. Raeder, L. Lin, K. Germaschewski, Y. Ge,, (UNH), T. Fuller-Rowell, N. Muriyama (NOAA/SEC), F. Toffoletto, A. Chan, B. Hu (Rice U.), M.-C. Fok, A. Glocer (GSFC), A. Richmond, A. Maute (NCAR)

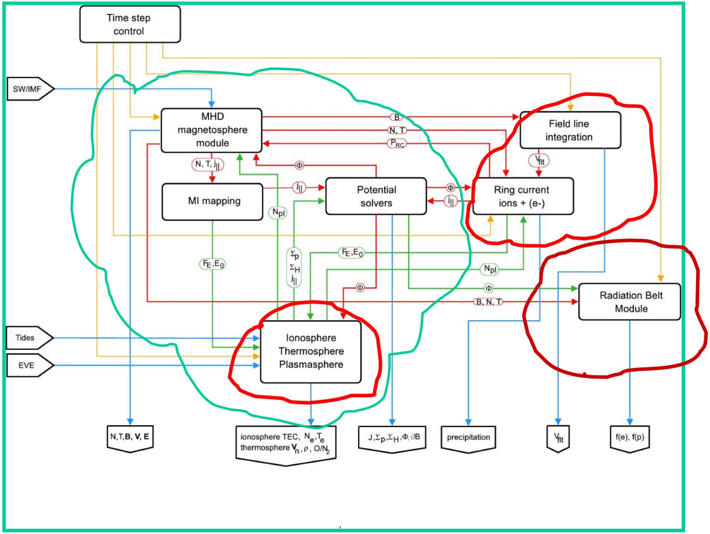
Developers, Contributors & Stakeholders

- **UNH:** Jimmy Raeder, Kai Germaschewski, Doug Cramer (core maintainers).
- **NOAA/CU:** Tim Fuller-Rowell, Naomi Maruyama (CTIM, IPE (ionosphere-plasma-electrodynamics) sub models).
- **Rice:** Frank Toffoletto, Stan Sazykin, Bei Hu (RCM sub model).
- **GSFC:** Mei-Ching Fok (CRCM and RBM sub models).

OpenGGCM facts

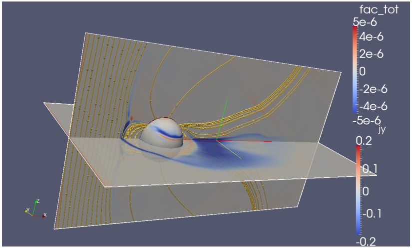
- OpenGGCM has been community model at CCMC since 2001. To date ∼600 runs on demand, ∼100 unique users.
- Number of papers that include OpenGGCM results approaching 100.
- Current version 4.0 delivered in 2011.
- Current version includes RCM/CRCM sub models, but these are currently not offered for runs-on-demand.
- Development was funded under various NASA and NSF grants, in particular a 2006 LWS/SC grant.

OpenGGCM structure



Our deliverable

Next-generation OpenGGCM



- modular architecture (based on LIBMRC)
- options for fluid plasma models (MHD, XMHD, multi-fluid, pressure tensor closures)
- adaptive mesh refinemnt
- implicit time integration
- Coupled to CTIM, RCM, CRCM, ...

New components available as open source, whole model to be delivered to CCMC.

LIBMRC

LIBMRC

LIBMRC started out as a collection of commonly used code for solving domain-decomposed PDEs. It forms the basis of three large codes: MRCV3, PSC and OPENGGCM.

LIBMRC is a framework – *kinda*.
You can use as little, or as much from it as you like.

Main Features

- provides a parallel object model (incl. checkpointing)
- domain decomposition of structured grids incl. communication and load balancing.
- parallel I/O
- code generation
- interface to python

Core features are fairly mature, but there is still a lot of active development.

Computers then and now

Cray X-MP/48 (1986), 800 MFlops

Computers then and now

Cray XK7 “Titan”

- 18,688 nodes
- 1 16-core AMD 6274 CPU per node (299,008 cores, 2.3 PetaFLOPS peak)
- 1 NVIDIA Tesla K20 GPU per node (50,233,344 cores, 22 PetaFLOPS peak)
- total system: $\approx$ 24 PetaFLOPS peak
- $\Longrightarrow$ 90 % of computational capability provided by GPUs

LIBMRC features

MRC_DOMAIN

"simple" and "multi" handle decomposition of a logically rectangular domain onto a given number of MPI processes.

"mb" provides a multi-block domain layout with flexible connectivity (cylindrical, butterfly, cubed sphere grid).

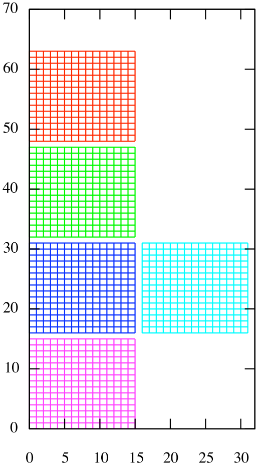
"amr" provides quad-tree / oct-tree based adaptive mesh refinement with support for staggered grids.

MRC_FLD

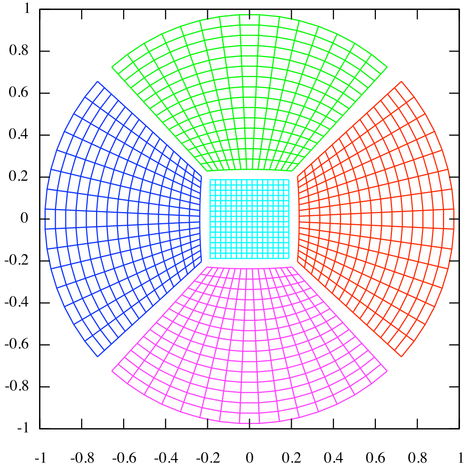
provides multi-dimensional arrays in C, with support for different data types / layouts.

Butterfly grid

Multi-block domain



logical



physical

LIBMRC: MRCV3

MRCV3 is a finite-difference based extended MHD code that supports arbitrary curvilinear geometries and implicit time integration.

It has currently no provisions for handling shocks.

Implicit time integration is implemented through LIBMRC's optional interface to PETSc's linear and nonlinear solvers.

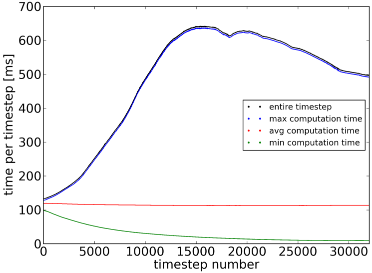
Particle-in-cell Simulation Code

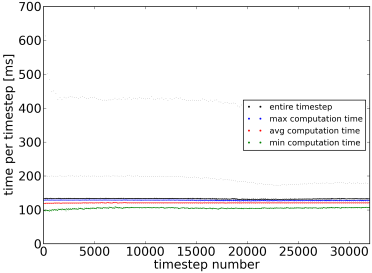
Plasma Simulation Code (PSC)

- 3D and reduced spatial dimensions (1D, 2D)
- explicit, relativistic, electromagnetic
- boost frame, moving window, PMLs, collisions, ionization...
- open boundary conditions (almost...)
- support for GPUs
- modular architecture: switching from legacy Fortran particle pusher to GPU pusher can be done on the command line.

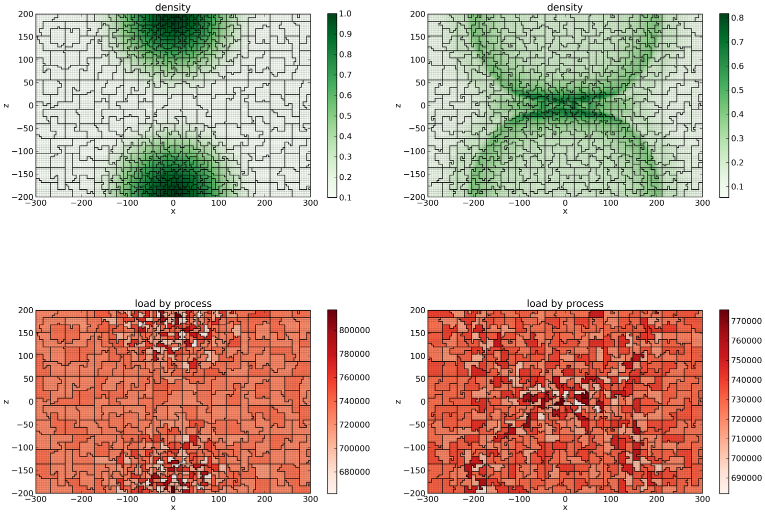
original version developed by H. Ruhl

PSC: load balancing





PSC: load balancing



Plasma fluid models in OpenGGCM

It is now possible to replace the existing MHD solver in OpenGGCM with various options:

- CWENO + CT (Ziegler, 2004)
- VL + CT (Stone & Gardiner, 2009)
- direct coupling to ATHENA
- on the way: couple to GKEYLL multi-fluid code

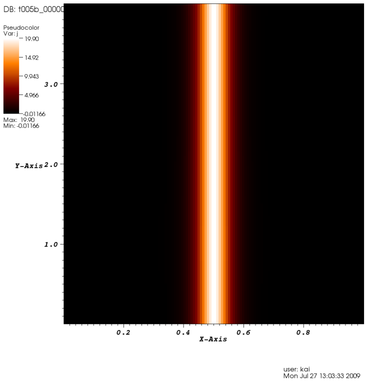
Orszag-Tang test run in GGCM_MHD

(Loading ot.mp4)

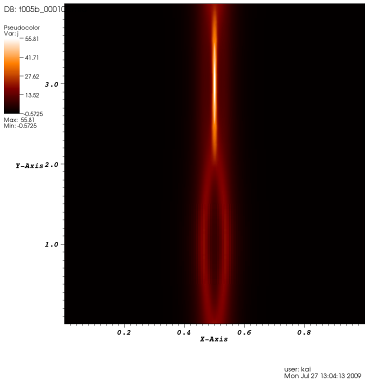
Lessons learned from ATHENA coupling:

- The actual coupling of the ATHENA integrators into LIBMRC/GGCM_MHD was fairly straightforward, and required minimal modifications to ATHENA's source.
- Making the integrator work in OpenGGCM required some changes internal to ATHENA (masking).
- Running a global magnetosphere simulation, however, ...
- More challenges: Boris correction, subtracting the dipole(?)

AMR-MRC – secondary tearing

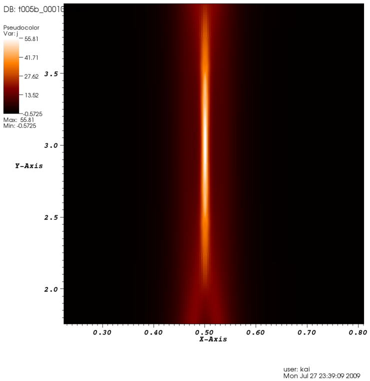


$t = 0$

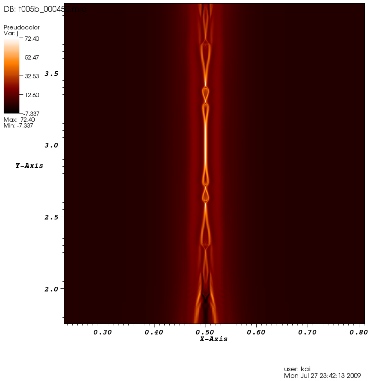


$t = 10$

AMR-MRC – secondary tearing – zoom

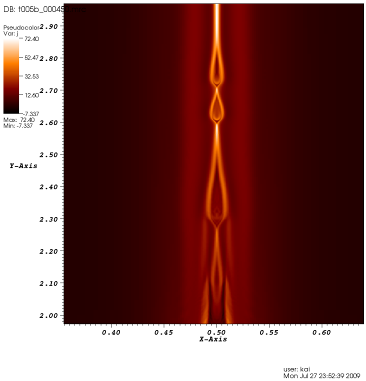


$t = 10$

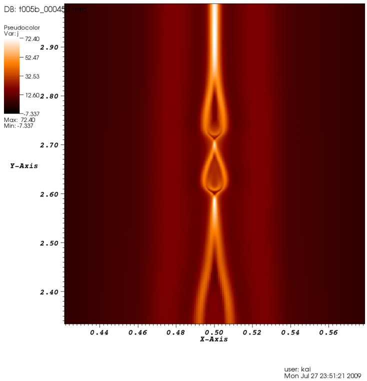


$t = 45$

AMR-MRC – secondary tearing – zoom

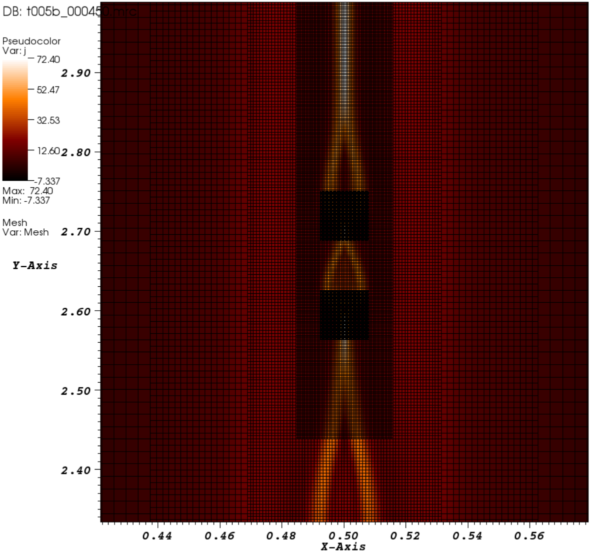


$t = 45$



$t = 45$

AMR-MRC – secondary tearing – zoom with grid cells



LIBMRC: staggered AMR

- Electromagnetic wave propagating across AMR grid using FDTD scheme on the Yee grid.

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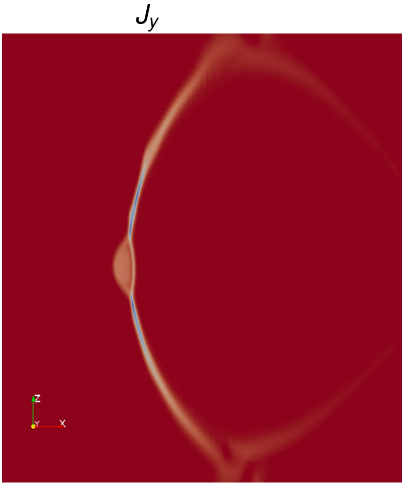
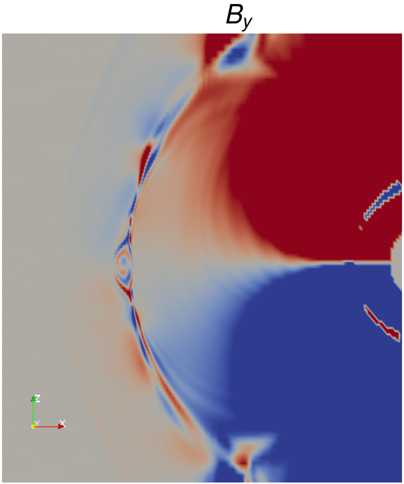
Quadrupolar out-of-plane magnetic field with Hall

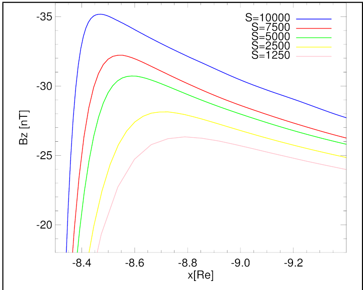


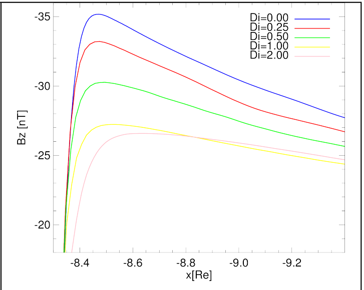


Hall-OpenGGCM initial results – flux pileup

- For the purely resistive case, we essentially reproduce the results of Dorelli et al. (2004). Subsolar reconnection proceeds via a flux-pileup mechanism. Field measurements along the sun-earth line are in qualitative agreement with profiles of upstream field derived analytically.
- For the high-Lundquist number S runs, as d_i increases, we also observe that pile-up is suppressed. The simulations shown here resolve the magnetopause at resolutions of up to 104 grid cells per R_E.

$D_i = 0$	$S = 10000$



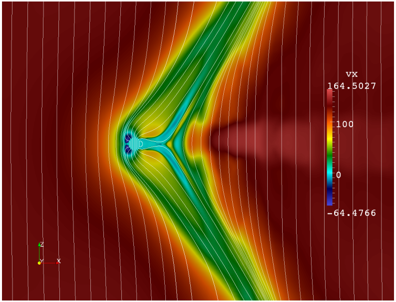


Benchmark with BATSRUS

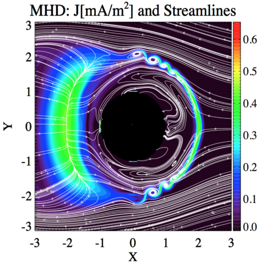
Ganymede

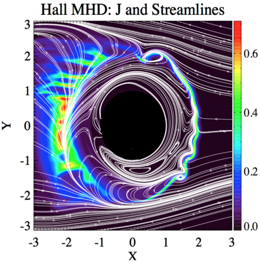
Ganymede is Jupiter's third moon. It has its own intrinsic magnetic dipole field and orbits in Jupiter's magnetosphere providing the equivalent to a constant, almost southward IMF.

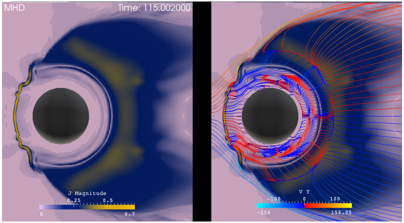
The size of Ganymede's magnetosphere is of the order of $10d_i$, which means that Hall effects play an important global role and resolving d_i is much cheaper than at Earth, making for interesting physics and a good computational benchmark.
(Dorelli, Glocer et al., submitted)

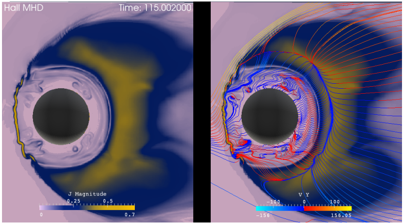


Cuts in the equatorial $z = 0$ plane

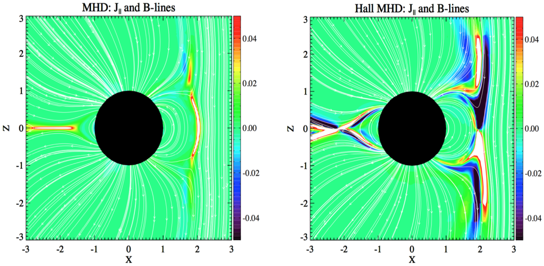


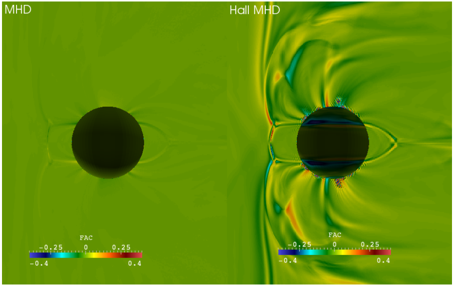






Cuts in the meridional $y = 0$ plane





Summary

- We have created the basic modular next-generation OpenGGCM, using LIBMRC.
- New plasma fluid solvers have been implemented.
- V & V, benchmarking is underway.
- Computational plans for next year:
  - couple to GKEYLL multi-fluid closure code
  - adaptive mesh refinement